(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: 0 232 923 A1

(12) EUROPEAN PATENT APPLICATION

(21) Application number: 87200004.7

(22) Date of filing: 05.01.87

(51) Int. Cl.4: H01M 2/16 , C25B 13/08

(30) Priority: 08.01.86 GB 8600401

(43) Date of publication of application:
19.08.87 Bulletin 87/34

(84) Designated Contracting States:
AT BE CH DE ES FR GB GR IT LI LU NL SE

(71) Applicant: HYDROGEN SYSTEMS N.V.
Koolmijnlaan 201
B-3560 Beringen(BE)

(72) Inventor: Vandenborre, Jan-Baptist Hugo, Dr.
Grootreesdijk 61
B-2460 Kasterlee(BE)

(74) Representative: van Reet, Gustaf, Dr.Ir.
Populierenlaan 14
B-2460 Kasterlee(BE)

(54) Improved ion-permeable diaphragms for electrolytic cells.

(57) Improved diaphragms for electrolytic cells which comprise a woven organic fabric embedded in a film forming mixture consisting of a particulate inorganic hydrophilic material and an organic polymeric binder as well as a method of producing the same which comprises the steps of i) intimiately mixing the particulate inorganic hydrophilic material with a solution of the polymeric binder in an appropriate solvent to form a slurry; ii) uniformly spreading said slurry on an inert flat surface to form a wet sheet; iii) immersing the stretched organic fabric into the wet sheet; iv) allowing the solvent to evaporate and optionally further eluting the solvent, and v) removing the dry sheet from the flat surface.

EP 0 232 923 A1

IMPROVED ION-PERMEABLE DIAPHRAGMS FOR ELECTROLYTIC CELLS

This invention is concerned with a new and improved type of diaphragm for electrolytic cells and with a method of producing the same.

More specifically, the invention is concerned with ion-permeable diaphragms which comprise a woven organic fabric embedded in a film forming mixture consisting of a particulate inorganic hydrophilic material and an organic polymer binder. In comparison with the diaphragms presently in use, the diaphragms according to the invention show distinct advantages as will be explained in more detail herebelow.

In the literature concerning electrochemical cells a distinction is often made between diaphragms and membranes based on the mechanism by which ions permeate the separation wall. The permeation of diaphragms by ions is meant to be diffusion-controlled while that of membranes is meant to be based on an ion-exchange mechanism. In many cases, however, both mechanisms will be involved. As used throughout the present specification and in the claims, the term "diaphragm" is meant to include both diffusion-controlled and ion-exchange-controlled separation walls for electrochemical cells.

Ion-permeable diaphragms have, during the last years, been increasingly used in electrochemical cells. Their function is essentially to separate both electrodes of an electrochemical cell in such a manner that ionic conductivity is kept optimal while intermixture of the, usually gaseous, reaction products formed at the surface of the electrodes is prevented. For example, in the electrolysis of water, hydrogen gas evolves at the cathode and oxygen gas at the anode. Quite evidently, mixing of both gases must be prevented in order to produce them in pure form, and, not in the least, to prevent the formation of a highly explosive gas mixture.

For an effective and safe operation of an electrochemical cell, it is therefore of the utmost importance to have it equipped with a diaphragm which is persistent and inert under the conditions of operation while displaying good ionic conductivity and being virtually impermeable for the gaseous reaction products. In the past, various types of diaphragms have been tried and actualy used. Thus far, none of them has been found completely satisfactory, as they all suffer from one or more disadvantages, which are usually inherent to the nature of the materials used and the structure and/or conformation of the diaphragms under consideration. For many years, asbestos diaphragms have been most widely used. One of their most important disadvantages is their capacity to swell, deform, dissolve and eventually prolaps in a hot alkaline aqueous environment.

Hence, substantially greater inter-electrode distances and lower working temperatures than otherwise required will be necessary, resulting in the necessity to apply higher voltages and consequently in an important loss of energy. Moreover, in more recent times, the use of asbestos has become under more and more severe attack because of its proven health-hasards. These are specifically threatening people in regular contact with it, for instance, workers in factories where such products are produced or used.

Consequently, attempts have been made to replace asbestos by more efficient and less hazardous materials. Two types of materials which have been tried extensively -both separately and in various combinations with each other-are inorganic wetting substances on the one hand and organic polymers on the other hand. Often used inorganic wetting agents are, for example, the chemically stable oxides and hydroxides of metals like Zirconium, Titanium, Antimony etc. They are usually completely inert, even under extreme conditions of pH and at high temperatures. They show excellent wetting properties. The problem though is, that the production of porous diaphragms possessing sufficient mechanical resistance starting from these materials is far from easy.

Indeed, diaphragms made e.g. of sintered inorganic material, as described in U.S. Pat. No. 3,490,953 are in general too brittle. Sheets of porous polymer materials on the other hand are more flexible and more resistant to mechanical damage. Unfortunately, until now, their use has not been very succesfull, mainly due to the hydrophobic character of the used polymer materials. Even if the pore structure is right, the solvalted ions of the electrolyte are not going to migrate easily through the diaphragm, causing great Ohmic losses over the diaphragm and a drastic decrease in cell performance. In gas evolving electrochemical cells, there is also the problem of adhering gas bubbles to the diaphragm surface, which may result in "hot spots" and deterioration of the diaphragm.

One of the solutions that have been put forward for reducing the hydrophobic nature of the polymer is by grafting hydrophilic chains, which contain ionizable groups, onto the polymer backbone. By doing so, the diaphragms swell in aqueous solutions and become permeable to ions. However, as a function of time, these diaphragms exhibit an increase of ionic resistance, which is mainly due to

a continuous loss of ionizable groups. Due to their short lifetime, diaphragms of this type - i.e. homogeneous polymeric diaphragms -have not found wide application. Heterogeneous diaphragms, comprising particulate wetting agents of an organic or inorganic nature, have proven more successfull in this respect. Examples of particulate wetting agents, which have been incorporated in diaphragms for electrolytic cells, include, for example, organic ion exchange resins and inorganic ion exchangers like Zirconium phosphate, Zirconium oxide, Zirconium hydroxide, Antimony oxide, Polyantimonic acid etc.

In order to give better strength to diaphragms of inorganic material, certain techniques have been developed whereby the particulate inorganic material is fixated in the open structures of a woven or non-woven matrix. Descriptions of various diaphragms which comprise inorganic wetting agents in an organic polymeric sheet will be found, for example, in the following references :

British Patent Nos. 1 081 046 and 1 503 915 and European Patent Application No. 96, 991.

Inversely, there have also been described diaphragms consisting of an inorganic cloth which has been reinforced with a precipitate of polymeric material (see e.g. U.S. Pat. No. 4,233,347).

The methods used to give appropriate porosity to polymeric diaphragms include, for example, stretching of pre-formed films, dissolving and washing out particulate fillers from polymer sheets and preparing films by means of a so-called casting technique. According to this technique, a diluted solution of the polymer, if needed mixed with the desired wetting agent, is spread as a thin layer onto a flat surface, e.g. a glass plate, whereupon the solvent is removed by heating and/or extraction with a solvent in which the polymer does not dissolve. A detailed description of this technique will be found e.g. in U.S. Pat. No. 3,463,713.

By combining an appropriate polymer with an appropriate wetting agent and by forming the diaphragms under suitable casting conditions, diaphragms of good quality can be made. One example of such good quality diaphragms consisting of a polysulfone polymer and polyantimonic acid is described in Brit. Pat. No. 1,545,454 and an improved method of producing them will be found in Brit. Pat. No. 2,045,804. Such diaphragms have indeed been found very effective in use.

Nevertheless, they still have a meaningful disadvantage in that they show a strong tendency to lose their flat structure upon being removed from the casting plate.

Apparently, certain tensions are being built up when the sheet is dried, resulting in an uncontrolled and irregular shrinking. For the good functioning of an electrochemical cell, the perfect flatness of the diaphragm is a prerequisite in order to guarantee a uniform contact all over the electrode surface. Insufficient local contact will allow gas accumulation in the available space, resulting in increased electrical resistance, "hot spots", perforation and irreparable damage.

In view of this shortcoming of the above-described casted diaphragms, problems arise during the manufacturing process and afterwards during storage. Eventually, a considerable percentage of the diaphragms do not meet the requirements. A particular disadvantage of the concerned diaphragms is that they cannot be stored in dry form. In theory, it would be possible to render the deformed sheets flat again under pressure but such has been found to destroy the required porosity of the diaphragms.

By the present invention, there is provided a new type of diaphragms for use in electrolytic cells which is devoid of all of the abovementioned disadvantages. Indeed, the diaphragms according to the invention maintain their flat structure, even upon drying. They show an excellent conductivity for ions and keep this property almost unaffected during a long period of operation. They combine flexibility with a high degree of mechanical strength. Manufacture is easy and, in principle, no dedicated materials or equipment are needed.

Essentially, the diaphragms according to the invention comprise an organic fabric which is embedded in an ion-permeable material consisting of a mixture of a particulate inorganic hydrophilic material and an organic polymeric binder.

Depending on the circumstances and the specific requirements of the actual application, each of the components may vary in composition and appearance.

As an organic fabric there may in principle be used any type of woven or non-woven organic fabric made of fibrous material which is inert under the conditions of use of the diaphragm (e.g. pH and temperature), made of fibres having a diameter of less than 1 mm and preferably less than 0.5 mm. The size of the interstices of the fabric are in general not critical but should preferably be smaller than 4 mm² and more preferably smaller than 1 mm² (1 x 1 mm). Polymeric fibre materials which can advantageously be used in the preparation of diaphragms according to the invention include, for example, co-polymers of ethylene and per-halogenated ethylene, e.g. monochlorotrifluoroethylene. One such polymeric fabric is produced by Allied Chem. Corp. and made available under the tradename HALAR ®. In a preferred embodiment of the invention, the fabric used is of the woven type.

As particulate hydrophilic inorganic materials there may for example be used oxides and hydrous oxides of metals selected from the following groups of the periodic table of the elements : III-A, III-B, IV-A, IV-B, V-A, V-B, VI-B, VII-B, VIII, the Lanthanide series and the Actinide series. Amongst the foregoing, the oxides and hydrous oxides of Zir conium, Antimony, Nickel, Bismuth and Zinc are particularly preferred. Especially preferred wetting agents are Zirconium oxide, Antimony oxide and poly-antimonic acid.

Obviously, mixtures of various oxides and hydroxides may be used where appropriate. The required grain size of the inorganic material may also depend on the circumstances but should preferably be smaller than 5 μm and most preferably smaller than 1 μm.

As an organic binder there may be employed any type of organic material which is stable under the conditions of operation of the diaphragm, and which can be dissolved in and precipitated from a solvent which in turn does not attack the woven support and the inorganic oxide or hydroxide. Examples of binding substances which may be employed successfully include fluorocarbon polymers like polyvinylidene fluoride, polytetrafluoroethylene, polysulfone, polypropylene, polyvinyl chloride, polyvinylbutyral etc. In order to dissolve these polymeric materials, there can be used, for example, organic solvents like dimethylformamide, dimethylacetamide, dimethylsulfoxide, N-methyl-2-pyrrolidone, mono-and diethyl ethers of ethylene glycol, ketones like methyl-ethyl ketone. The choice of an appropriate solvent is a matter of routine trial but, in general, the solubility characteristics of a particular polymer in various solvents will be sufficiently documented to make further experiments in this respect superfluous.

In order to obtain diaphragms which combine adequate mechanical strength with sufficient ion-permeability, the proportion of inorganic material to organic binder must be kept within certain limits. A too low proportion of inorganic hydrophilic material will result in an unacceptably high resistance of the diaphragm. A too high proportion on the other hand will make it too brittle and fragile. Experimentally, it has been determined that, for an appropriate functioning of the diaphragm, its content of inorganic hydrophilic material as specified hereabove, should be at least about 8 % by weight.

To avoid impairing the mechanical strength of the diaphragm, the inorganic hydrophilic material will appropriately be kept below 95 % and preferably below 90 % by weight. Preferred diaphragm materials comprise, for example, from about 60 to about 90 and most preferably from about 75 to about 85 % by weight of inorganic hydrophilic material.

Obviously, the diaphragm according to the invention may contain other elements besides those mentioned as essential components, insofar they do not negatively influence the characteristics.

Diaphragms according to the invention are conveniently prepared by a process comprising the steps of :

i) intimately mixing the particulate inorganic hydrophilic material with a solution of the polymeric binder in an appropriate solvent to form a slurry;

ii) uniformly spreading said slurry on an inert flat surface to form a wet sheet;

iii) inmersing the stretched organic fabric into the wet sheet;

iv) allowing the solvent to evaporate and optionally further eluting the solvent, and

v) removing the dry sheet from the flat surface.

In order to prepare a uniform diaphragm of appropriate thickness and porosity, the thickness of the wet sheet and the concentration of the diaphragm forming mixture in the solvent must be well chosen. In order to allow appropriate spreading, the slurry may not be too viscous and preferably contain no more than 60 % of the film forming mixture.

The thickness of the wet sheet is preferably less than 2 mm, in particular less than 1.5 mm. The flat surface on which the sheet is spread may, in principle, be made of any non-porous inert material from which the sheet can be easily removed afterwards. Glass plates lend themselves particularly well for this purpose but metal or organic polymeric surfaces can be used as well.

The immersion of the woven support into the wet sheet must be carried out with care, particularly in order to avoid the introduction of air bubbles into the sheet. It is therefore important that the fabric is well stretched, e.g. on a frame and the fabric must be kept stretched during the removal of the solvent. During the immersion operation, the fabric should preferably be kept separated from the support, e.g. at a distance of about 200 μm. The solvent may be removed by evaporation and/or lixiviation. Elevated temperatures may be employed to accelerate the evaporation process. Lixiviation may be carried out in any liquid in which the primary solvent dissolves and which does not interfere with the chemical or physical stability of the fabric or the organic binder. Optimal results have been obtained by removing the solvent by mere lixiviation. When the solvent is water soluble, e.g. dimethylformamide, dimethylacetamide, N-methyl-2-pyrrolidone or dimethylsulfoxide, lixiviation is properly carried out by immersing the casted plate in a water bath.

The diaphragms composed and prepared as described hereinabove have been found very effective for use in electrolytic cells, especially for the alkaline electrolysis of water and in alkaline fuel cells. They preserve their functional properties during a long period of operation under normal circumstances and can be stored for a long time, even in dry form.

The invention is further illustrated by the following examples which are not intended to limit the scope thereof.

Example I

A well mixed suspension consisting of 60 wt % N-methyl-2-pyrrolidone, 32 wt % Zirconium oxide and 8 wt % polysulfone UDEL®, manufacturer Union Carbide, was casted on a glass plate to produce a wet sheet with a thickness of 750 μ and surface area of 0.5 m^2. Immediately after casting, a woven fabric consisting of a copolymer of ethylene and monochlorotrifluoroethylene (HALAR ®, manufacturer Allied Chemical Corporation; thickness 300 μ), stretched on a frame, was immersed into the wet sheet at a distance of 100 μ from the plate. The plate was transferred into a water bath and allowed to lixivitate at room temperature for 20 minutes. The lixiviated sheet was peeled from the plate and kept under water for another 15 minutes. The thus formed diaphragm had a thickness of about 500 μ. The diaphragm showed excellent flatness and a very good conductivity for ions when used in an electrochemical cell.

Example II

Ion-permeable diaphragms according to the invention are prepared by repeating the procedure of example I and using respectively the following film forming slurry.

a) Antimony oxide 26 %
Polyvinylidene fluoride 8.7 %
Methylethylketone 63.3 %

b) Antimony oxide 32 %
Polysulfone 8 %
N-methyl-2-pyrrolidone 60 %

Claims

1. An ion-permeable diaphragm comprising an organic fabric embedded in a film forming mixture of a particulate inorganic hydrophilic material and an organic polymeric binder.

2. An ion-permeable diaphragm according to claim 1 wherein the said particulate inorganic hydrophylic material is an oxide or hydroxide of a metal selected from the classes III-A, III-B, IV-A, IV-B, V-A, V-B, VI-B, VII-B, VIII, the Lanthanide and the Actinide series of the periodic table of the elements.

3. An ion-permeable diaphragm according to claim 2 wherein the said particulate inorganic hydrophilic material is an oxide or hydrous oxide of Antimony, Zinc, Zirconium, Titanium or Bismuth.

4. An ion-permeable diaphragm according to any one of claims 1 to 3 wherein the said organic fabric is made of fibres having a diameter of less than 1 mm and said organic fabric has interstices of less than 4 mm2.

5. An ion-permeable diaphragm according to any one of claims 1 to 4 wherein the said film forming mixture contains at least 8% of the said particulate inorganic hydrophilic material.

6. An ion-permeable diaphragm according to any one of claims 1 to 5 wherein the said film forming mixture contains from 60 to 95% of the said particulate inorganic hydrophilic material and wherein the said inorganic hydrophilic material has a grain size of less than 5 micrometer.

7. An ion-permeable diaphragm according to any one of claims 1 to 6 wherein the said particulate inorganic hydrophilic material is an oxide or hydrous oxide of Antimony or Zirconium, the said organic material is made of a co-polymer of ethylene and monochlorotrifluoroethylene and the said organic polymer binder is a fluorocarbon polymer, a polysulfone, polypropylene, polyvinyl chloride or polyvinylbutyral.

8. A process of preparing an ion-permeable diaphragm as defined in any one of claims 1 to 7, comprising the steps of:

i) mixing the particulate inorganic hydrophilic material with a solution of the polymeric binder in an appropriate solvent to form a slurry;

ii) uniformly spreading said slurry on an inert flat surface to form a wet sheet;

iii) immersing the stretched organic fabric into the wet sheet;

iv) removing the solvent by evaporation and/or lixiviation; and

v) removing the sheet from the said surface.

9. A process according to claim 8 wherein the said solvent is selected from the group consisting of dimethylformamide, dimethylsulfoxide, dimethylacetamide, N-methyl-2-pyrrolidone and methyl-ethylketone.

10. A process according to any one of claims 8 and 9 wherein the solvent is removed by lixiviation.

European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 87 20 0004

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
X	US-A-3 817 772 (HEIT) * Column 4, lines 16-31; column 5, lines 12-35,50-58; column 8, lines 1-7; claims 1,10,11 * ---	1,5,6	H 01 M 2/16 C 25 B 13/08
X	US-A-4 371 596 (SHEIBLEY) * Column 4, lines 41-62; column 5, lines 13-29; column 6, lines 11-30 * ---	1-3,5 6	
X	DE-A-2 529 153 (ICI LTD) * Page 7, lines 12-15; example 1 * ---	1-3,5	
X	US-A-3 890 417 (VALLANCE) * Example 2; claims 1,12,19,22,27,28 * ---	1-3,5	**TECHNICAL FIELDS SEARCHED (Int. Cl.4)**
X	PATENT ABSTRACTS OF JAPAN, vol. 6, no. 119 (E-116)[997], 3rd July 1982; & JP-A-57 46 465 (FURUKAWA DENKI KOGYO K.K.) 16-03-1982 * Abstract * --- -/-	1-3,5	H 01 M C 25 B C 08 J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	02-04-1987	COOK S.D.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
& : member of the same patent family, corresponding document

European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 87 20 0004

Page 2

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
X	CHEMICAL ABSTRACTS, vol. 83, no. 22, 1st December 1975, page 188, abstract no. 182070s, Columbus, Ohio, US; & JP-A-75 64 739 (TOKYO SHIBAURA ELECTRIC CO., LTD) 02-06-1975 * Abstract * ---	1-3,5	
X	PATENT ABSTRACTS OF JAPAN, vol. 6, no. 176 (E-130)[1054], 10th September 1982; & JP-A-57 95 071 (FUJIKURA DENSEN K.K.) 12-06-1982 * Abstract * ---	1,2,5	
Y,D	GB-A-2 045 804 (STUDIECENTRUM VOOR KERNENERGIE) * Page 1, lines 1-46; page 3, lines 24-30 * ---	1,8-10	TECHNICAL FIELDS SEARCHED (Int. Cl.4)
Y	CHEMICAL ABSTRACTS, vol. 83, no. 8, 25th August 1975, page 120, abstract no. 60886s, Columbus, Ohio, US; & IN-A-109 715 (INDIA MINISTRY OF DEFENCE) 09-11-1968 * Abstract * ---	1,8-10	
A	GB-A-1 197 357 (VEB FARBENFABRIK WOLFEN) * Page 2, lines 100-120; claim 1; page 3, lines 62-65 * --- -/-	1,4,8	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	02-04-1987	COOK S.D.

CATEGORY OF CITED DOCUMENTS

- X : particularly relevant if taken alone
- Y : particularly relevant if combined with another document of the same category
- A : technological background
- O : non-written disclosure
- P : intermediate document
- T : theory or principle underlying the invention
- E : earlier patent document, but published on, or after the filing date
- D : document cited in the application
- L : document cited for other reasons
- & : member of the same patent family, corresponding document

EPO Form 1503 03 82

European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 87 20 0004

DOCUMENTS CONSIDERED TO BE RELEVANT

Page 3

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
A	FR-A-2 546 535 (INSTITUT NATIONAL DE RECHERCHE CHIMIQUE APPLIQUEE) * Claims 1,2,4; example 5 * ---	1-3,7	
A	US-A-4 072 793 (WATANABE et al.) * Column 2, lines 9-37 * -----	1,4,7	

TECHNICAL FIELDS SEARCHED (Int. Cl.4)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	02-04-1987	COOK S.D.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO Form 1503 03 82